Discussion of an Ecosystem Functional Basis for Protecting Receiving Waters

L. S. Coffman [1]

[1]Associate Director, Programs and Planning Division, Prince George's County, Maryland, 20774; PH (301)883-5839; FAX (301) 883 9218; lscoffman@co.pg.md.us

Abstract

This paper is intended to provoke thinking about the efficacy of current technology and the need for new tools to meet one of our more challenging objectives of protecting the ecological integrity of our receiving waters. Included is a discussion of the limits or our current technology and some basic philosophical and scientific principles of a new emerging ecosystem-based approach to the protection of receiving waters. This new approach has evolved from the development, use and study of Low Impact Development (LID) decentralized stormwater management technologies. The primary goal of LID (for new urban development) is to mimic the predevelopment hydrologic regime to better protect streams from hydrodynamic stresses universally associated with urbanization. To mimic the predevelopment hydrology requires a much more thorough understanding of hydrologic / ecological processes at work within each unique watershed and the complex interrelationships of the terrestrial and aquatic ecosystems. The process of urbanizing (or any land use change) essentially destroys, disrupts, and diminishes the capacity of the terrestrial ecosystem to detain, store, evaporate, infiltrate and cleanse runoff. The adverse impacts of urbanization are not absolute or inevitable but are a consequence of the poor state of our technology and the lack of understanding about ecological design and landscape / aquatic ecology.

Introduction

We have chosen to handle runoff and deal with environmental impacts in a very specific manner with very predictable often negative results and consequences. There is a need to change our thinking from the goal of reducing impacts commonly associated with watershed protection strategies to an ecosystem based approach that has the specific and clear goal of restoring a watershed's ecological functions. Only by reproducing predevelopment (natural) conditions is it possible to fully protect our waters and to ensure the ecological integrity of the aquatic ecosystem.

The definition of an ecologically based approach has evolved concurrently with development of LID technologies. As the number of LID principles and practices has expanded so has our understanding and ability to maintain and/or restore the landscape's capability to cycle water, assimilate nutrients and capture pollutants. Maintaining predevelopment ecological functions is a complex and ambitious goal that goes well beyond current approaches of just reducing impacts. It's an approach that is based in science integrating what we know about engineering, hydrology, pedology, biology, stream geomorphology, ecology, etc.

Many studies have shown that urbanization can adversely impact the ecological integrity of receiving waters   Adverse impacts are often associated with land use activities such as clearing of natural land cover, mass grading and increased impervious surfaces from residential, commercial and industrial developments. There is no question that there is a strong correlation between these land use activities and receiving water impacts. However, from a functional ecosystem based approached it is necessary to relate land use activities to the primary causes and effects that alter ecological functions and processes.

For example, if you believe that impervious cover "causes aquatic degradation" (Schuler 2003) then you might think that reducing impervious cover would reduce impacts. A more scientific and fundamental approach is to understand how we chose to use impervious cover and how that use alters vital ecological functions and processes i.e., hydrology, frequency of discharge, nutrient cycling, temperature regimes, energy flow, etc. Once you understand exactly how urbanization changes these processes / functions then given the right tools it is possible to engineer a site to restore the landscape's functionality.   If you want to restore ecological functionality, it is not enough to simply reduce or change land use activities, you must proactively intervene to design systems that restore functions and processes within the built environment.

Our efforts to reduce impacts with the use of BMP's or controlling land use activities or reducing impervious cover is not enough to prevent continued degradation of our receiving streams. The issue that we must face or consider is that our current BMP based impact reduction technology does not and cannot either restore or maintain the ecological integrity of our streams. Continued impacts will occur to receiving water through the cumulative impacts of our current non-anti-degradation approach. The case studies discussed below begin to shed some light on the limitations of current technology and the need to advance the state of the art.

Pacific Northwest (PNW) Research

Research in the PNW has shown that the ecological integrity of aquatic ecosystems are significantly degraded by the cumulative impacts of land use activities with or without conventional BMP's (May / Horner, 2000). Figure 1 clearly shows in that regardless of the use of BMP's (ponds in this case) as the total imperviousness area (TIA) increases the ecological integrity of the receiving water decreases.   This study is not conclusive but it does not show any clear benefits of using ponds to protect the ecological integrity of receiving streams. This is not to say that ponds have no benefits but they are difficult to quantify. Furthermore, it is not clear why the ponds in this study were not effective. They may not work because the approach is wrong or poor design, or improper construction or the lack of maintenance. Regardless of why they don't seem to work, ponds do not seem to be a good chose for protecting ecological integrity.

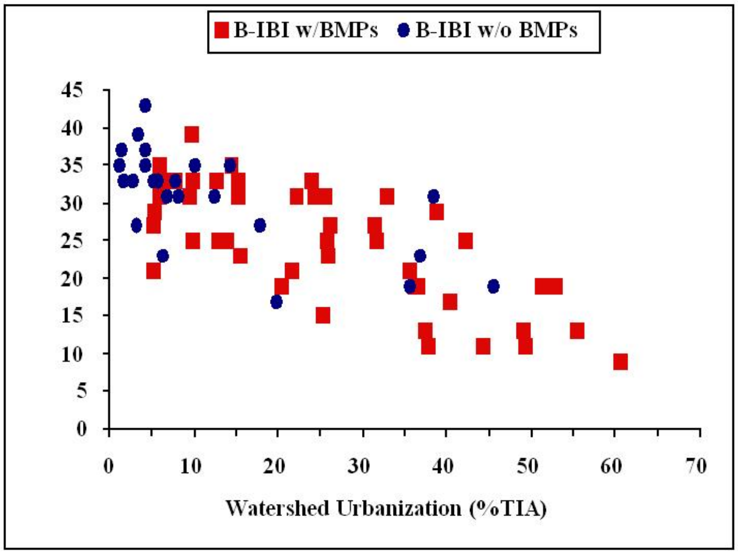

Figure 1. Relationship between watershed imperviousness and biological integrity, as measured by the multi-metric benthic index of biotic integrity (B-IBI), showing the lack of mitigating influence of structural BMPs on biologic conditions in Puget Sound lowland streams (Horner and May, 2000). Note, "w/BMPs" refers to structural facilities only.

Another study in the PNW by Horner and May indicates that other factors can have a positive impact on the ecological integrity streams such as riparian buffers. Figure 2 shows a graph of several watersheds where TIA, a fish IBI and riparian buffer were compared. One conclusion in this stud was that buffers could be an important factor in maintaining stream integrity. It was also apparent that sensitive species disappeared at TIA's of less than 5%. There are also some anomalies in the graph that show unexpected good integrity with rather high TIA levels. Further study of these outliers may provide important insights into how to maintain good ecological integrity with high levels of TIA.

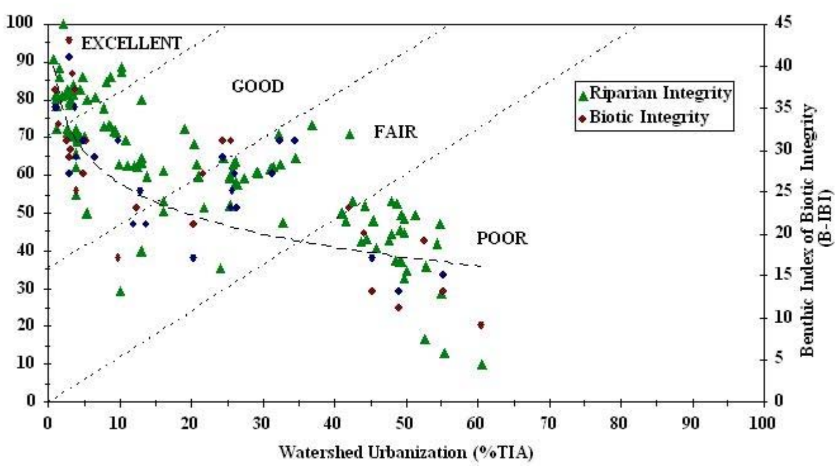

Figure 2. Honer and May, 2001 relating TIA and a coho / steelhead salmon IBI to stream buffers.

Reston Virginia Study

Buffers alone may not be sufficient to protect ecological integrity. A comprehensive watershed study undertaken by the City of Reston, Virginia in 2000 found that despite the use of clustered development with reduced TIA and increased riparian buffers the integrity of their streams were poor to marginal. Reston was a planned community built in the 1970's that used regional stormwater ponds and a conservation design with large riparian buffers of 150 to 300 feet wide. The buffers were designed as an important environmental amenity for the community, see Figure 3.

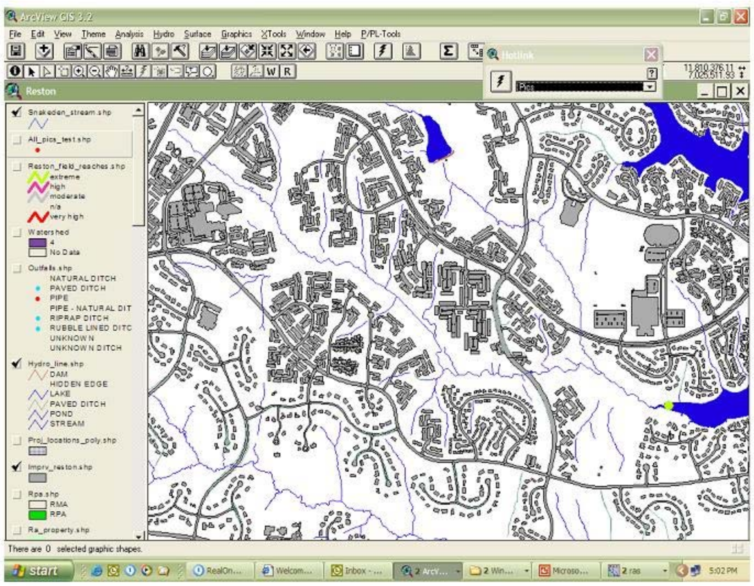

Figure 3. GIS map showing typical clustered development with extensive riparian buffers and regional stormwater management ponds.

The Reston study indicates that the cause of the poor biological integrity was directly related to hydrodynamic changes. All built areas are directly connected to the streams via pipes or concrete channels. The increase frequency of discharges, high flows, increased velocities and volume of runoff continued to erode streams banks / beds destroying instream habitat and associated biota.

Figure 4. Photographs of directly connected outfalls bypassing the wide riparian stream buffers.

The Reston conservation design resulted in streams devoid of viable aquatic communities and regional ponds that quickly fill with sediment requiring constant and expensive dredging. Reston's strategy to restore their streams is to retrofit the built areas with LID techniques and disperse runoff into the buffer areas reactivating them for storage and filtration of runoff.

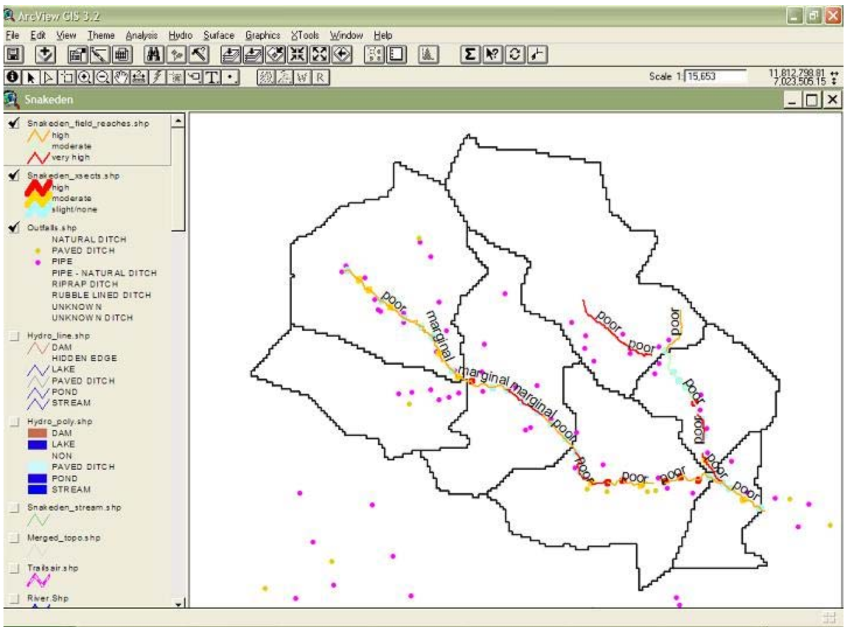

Figure 5 GIS Map showing results of IBI macroinvertabrate surveys. All streams were either poor or marginal and non-supporting

Prince George's County, Maryland Studies

Prince George's County is a Phase I Municipal Stormwater NPDES community and as such has been required to perform instream chemical water quality monitoring for last 10 years. The County also has a County wide biological assessment program based on the Maryland Department of Natural Resources macroinvertabrate IBI protocol. The water quality data has been collect in various watersheds and for varying land uses.

Wet Weather Monitoring

Maximum Concentrations at In-stream Stations

Parameter	EPA Criteria		L. Beaver-dam Cr.	Western Branch	Collington Branch
	chronic	acute			
Cadmium (ug/l)	1.1	3.9	40	1.0	10
Copper (ug/l)	12	18	470	30	57
Lead (ug/l)	3.2	83	1700	66	34
Zinc (ug/l)	110	120	5400	160	330
Total P (mg/l)	0.1		3.2	0.74	3.4
TKN (mg/l)	--		6.0	7.2	9.9
Nitrate (mg/l)	10		2.5	1.0	1.8
BOD (mg/l)	7		71	57	27
TSS (mg/l)	500		4800	910	2500
Fecal Coliform (org/100 ml)	200		220000	13000	17000
Oil/Grease (mg/l)	--		7	BDL	BDL

Figure 6. A summary of the first five years of data that shows heavy metals concentration all urban watersheds are many times higher than EPA's acute criteria.

Biological studies in these same watersheds show degraded and non-supporting biotic communities. It is the conclusion of theses biological and chemical studies that the impairment is in great part due to the high levels of toxic chemicals in the urban runoff.

Although the above case studies are not conclusive as to the primary cause and effect of the biological degradation, but it is clear that the impacts of urbanization are complex and most likely involve multiple stressors (hydrology, water quality and habitat structure) with each stressors having varying degrees of influence importance dependant on target species and their sensitivities, see Figure 7.

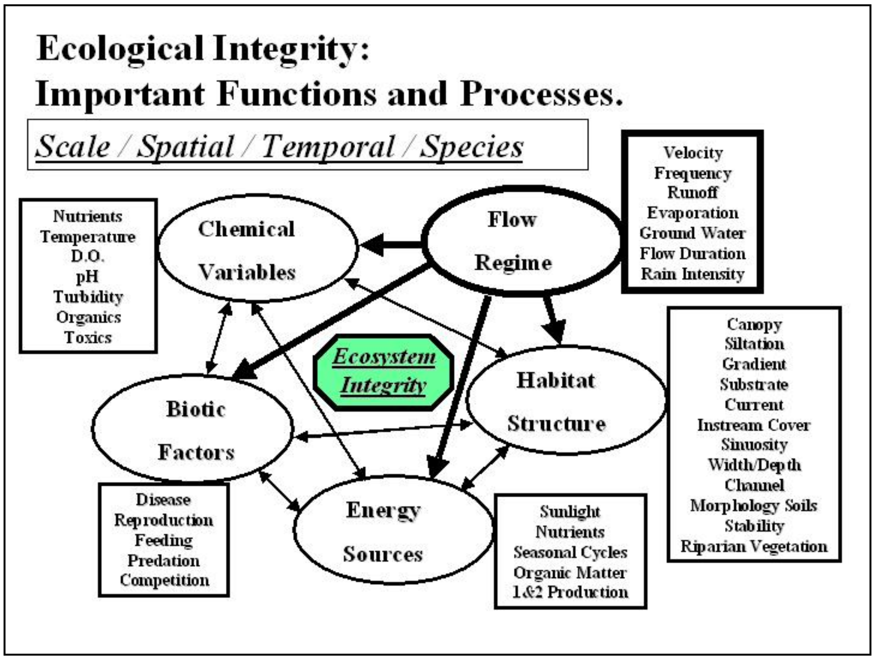

Figure 7 shows some of the major factors and complexities that can affect Impacting Ecological Integrity. Changing any factor may have an adverse impact on the ecological integrity.

Urbanization and the Cumulative Loss of Ecological Functions

From am ecological perspective urbanization causes a systematic loss of terrestrial ecosystem functions. The functions are lost through cumulative destruction of the landscape's water balance and ability to assimilate chemicals and energy. As we urbanizes we not only lose habitat but also vital ecological functions. What we have failed to realize is that the integrity of the aquatic ecosystem depends wholly upon and is a reflection of the functionality of the terrestrial ecosystem. The plant / soil / microbe complex controls a watershed's ability to:

1. Control hydrology through storage / evaporation / recharge / detention of rainwater.
2. Store and cycle nutrients and chemicals (phosphorous / nitrogen / carbon, organics, heavy metals.
3. Maintain water quality by filtering / buffering / degrading / immobilizing / detoxifying organic and inorganic materials.

Under natural land cover / soil conditions, there is little if any surface runoff except in all but the largest precipitation events. Once the ecological functions of the watershed are lost through the development process and use of conventional technologies the aquatic ecosystem begins to experience numerous stressors.

One important change in our thinking and understanding is that a watershed's land cover and soil flora and fauna are a living dynamic ecosystem with a complex structure and numerous functions that serve many vital ecological roles in protecting our receiving waters.

Conventional Stormwater Management Results in Loss of Ecological Functions

Generally, sites are developed using the "good drainage paradigm" getting water away from structures as quickly as possible. In the design of all built environments one basic guiding principle is to ensure that surfaces efficiently shed, collect and convey runoff. Runoff is collect and concentrated on rooftops, parking lots, streets, and sidewalks. Concentrated runoff is conveyed through swales, gutters, channels and pipes to centralized best management practices (BMP's) where it is treated or managed. We created an extremely efficient drainage conveyance system using impervious surfaces to help collect and convey runoff to an end-of-pipe BMP. This efficient drainage system is further helped by the fact that soils are compacted during construction and become devoid of much of its ecological structure, function and biological processes functioning more like concrete than soil.

Current stormwater management / drainage technology has developed in a reactionary fashion to solve problems that effect our property and physical safety, quality of life and to make our lives more convenient e.g., detention to control flow to reduce flooding, piping to reduce flooding and erosion and harden /pave surfaces to reduce erosion, mud and convey runoff safely to drainage systems. Unfortunately, the old stormwater management /drainage approaches where not intended or designed to solve ecological problems or to protect the ecological integrity of receiving waters.

Nevertheless we have tried to put bells and whistles on our detention ponds and use other end of pipe techniques to protect receiving waters. So far, after almost 30 years of experience with pipe and pond technology, it is difficult to measure its success or direct benefits. In fact, experience has shown that our current approaches may not be achieving what we had hope for and are creating additional environmental and economic liabilities.

LID's Basic Ecological Design Approach

LID's approach to control stormwater at the source allows one to begin to think about how to recreate the ecological processes of the natural terrestrial landscape within the built environment. LID is simply and intelligent and creative way to engineer any site in any watershed in a manner that mimics the predevelopment volume of storage, recharge, evaporation and runoff. The integration of a wide array of techniques into each lot allows one to restore a more natural water balance and hydrologic regime. Reconnecting the urban landscape / green spaces to the water cycle by optimizing the use bioretention thus allowing the urban landscape to filter, treat and cleanse contaminated runoff. LID's decentralized principles and practices are quite extensive. There are five basic design goals with almost an unlimited number of techniques or practice for each goal. The principles include: optimizing conservation of natural features and soils, minimization of impacts, strategic timing to maintain time of concetration, use of integrated uniformly dispersed small-scale management practices and optimizing pollution prevention practices. LID uses hydrology and water sensitive designs as an organizing principle in the design of every urban landscape, infrastructure and building feature.

When all aspects of the urban landscape is designed to create a positive impact on hydrology and water quality then it is just a matter of having enough practices to mimic the natural landscape's hydrologic functions and processes. The more practices that are integrated into the urban landscape the closer you get to restoring the predevelopment hydrologic regime.

Conclusions

A watershed's hydrology is controled by the unique land cover, geology and biology within the watershed. As development proceeds it systematically destroys the natural terrestrial functions replacing them with pipe and BMP technology that by it very nature cannot recreate the natural ecological functions.

We now have a choice. We can continue to design urban landscapes that are dysfunctional and disconnect from both the terrestrial and aquatic ecosystem or we can design urban landscape that recreate the water balance and remain a functioning part of the ecosystem. We can think about stormwater as a toxic waste product or as a resource that must be carefully managed to protect the aquatic ecosystem and to meet our water resources needs. It's your chose. Chose wisely.

For more information on LID technology see the list of web sites below.

References

Horner, J.R., May, C.R., et.al. 2001. Structural and Non-Structural BMPS for Protecting Streams. Watershed Management Institute.

May, C.W., E.B. Welch, R.R. Horner, J.R. Karr, and B.W. Mar. 1997a. Quality Indices for Urbanization Effects in Puget Sound Lowland Streams. Washington Department of Ecology, Olympia, WA, U.S.A.

Prince George's County Department of Environmental Resources. 1996. Long Term Water Quality Monitoring – Chemical and Biological

Prince George's County Department of Environmental Resources. June 1999. Low-Impact Development Design Strategies - An Integrated Design Approach

Prince George's County Department of Environmental Resources. July 1999. Low-Impact Development Hydrologic Analysis.

Stein, S., Saccone, D., Butler, L., Reston Watershed Management Plan, 2000. Reston Association.

Schuler,T. 2003. Impacts of Impervious Cover on Aquatic Ecosystems, Center for Watershed Protection

Web Sites of Interest

Prince George's County, MD Web Site –
http://www.goprincegeorgescounty.com/Government/AgencyIndex/DER/PPD/index.asp?h=20&s=&n=50

http://www.raingardens.org/
http://www.main.nc.us/riverlink/content/appendix/sitemap.htm
http://www.nrdc.org/water/pollution/gutter/execsum.asp
http://lowimpactdevelopment.org/
http://www.wa.gov/puget_sound/Programs/LID.htm
http://www.dakotaswcd.org/lid_fs.htm
http://for.communitypoint.org/downloads/LID_flyer_pg1.pdf
http://www.epa.gov/owow/nps/lidlit.html
http://www.werf.org/press/winter01/01w_low.cfm
http://www.saj.usace.army.mil/projects/StormWater/LID%20Overview%20Florida/
http://www.chesapeakecommunities.org/hampstead2.5.html
http://www.forester.net/sw_0101_innovative.html#innovation
http://www.wa.gov/puget_sound/Programs/lid_cd/web_links.htm
http://www.asu.edu/caed/proceedings98/Coffmn/coffmn.html
http://state.vipnet.org/dof/rfb/riparian/rain_gardens.htm
http://www.consciouschoice.com/environs/raingardens1405.html
http://www.porttowns.com/special/rain.html
http://www.epa.gov/owow/info/NewsNotes/issue42/urbrnf.html
http://www.horne.com/Landscap.htm